McDermott Technology, Inc. Research and Development Division

Realistic Solutions to Real-World Problems

SOFCo®

Clean energy for the world

A significant transformation has begun in the power generation industry, and SOFCo® is positioned to become one of the leaders in the emerging market. The traditional means of generating electricity – central processing plants – is being supplemented and, at times, displaced by distributed power generation. A number of factors are contributing to this trend, the most significant being utility deregulation and advances in small-scale power generation technologies. Of the distributed generation technologies, fuel cells are the most promising and SOFCo is positioned to lead the way.

History

In 1994, McDermott International, Inc., a leading worldwide energy services company, and Ceramatec, Inc., a recognized leader in the development of planar solid-oxide fuel cell (pSOFC) technology, formed SOFCo — a world-class team committed to rapidly developing and commercializing solid-oxide fuel cell (SOFC) power systems. In 1999, Advanced Refractory Technologies, Inc. (ART) in Buffalo, New York, joined the team. ART, now owned by the M/A-COM division of Tyco Electronics, is helping SOFCo develop a low-cost manufacturing process for SOFC ceramic stacks, adapting multilayer processing technology used in the electronic packaging industry. In January 2000, McDermott acquired 100% ownership of SOFCo.

The SOFCo team established a unique design that, combined with its high-quality, low-cost manufacturing process, will significantly improve performance and cost. The U.S. Department of Energy (DOE) recognized the advantages of our approach and, in September 1999, awarded McDermott Technology, Inc. (MTI) a contract for the first phase of a $20 million DOE-funded program (Contract DE-AC-26-99FT40691) called Affordable Manufacturing for Power Systems (AMPS). Phase 2 of this program was awarded in Sep-

A digital rendering of a commercial 250-kW solid-oxide fuel cell system being developed by SOFCo illustrates the compactness that can be achieved.

Fuel cell stack testing is a critical component of SOFCo's development program.

tember 2000 following successful completion of the first phase.

Why planar SOFC?

While all types of fuel cells offer benefits like high efficiency, reliability, low emissions, quiet operation, flexible siting, and fuel flexibility, planar solid-oxide fuel cells offer much more:

- Solid-state, ceramic construction eliminates problems of electrolyte containment and material corrosion
- High operating temperature greatly simplifies converting available fuels to the hydrogen required by fuel cells
- High-quality heat can be used for cogeneration or in combined-cycle applications

Commercialization

In August 2001, the DOE again recognized the merits of the SOFCo technology by selecting MTI and its partner, Cummins Power Generation, for an award under DOE's Solid-State Energy Conversion Alliance (SECA). The goal of this 10-year program is to develop 10-kW SOFC systems that can be produced for $400 / kW. The system is designed for liquid propane but will also operate on natural gas. A catalytic partial-oxidation reformer was selected for use, since eliminating the need for steam simplifies design and reduces overall size, weight, and cost of the refomer. SOFC systems meeting the SECA cost and performance goals will displace reciprocating-engine technology beginning with those currently used in recreational vehicles, commercial vehicles, and in standby telecommunication applications.

SOFCo is also targeting the stationary power generation market. Premium power applications that demand a high level of reliability and quality are of interest, particularly those where waste heat can be utilized.

Off-grid electricity is another attractive market for SOFCs. In developing countries, it is possible to avoid the costs associated with installing transmission and distribution lines, resulting in significant savings. As costs are reduced further, we will pursue mass markets in developed nations.

Contact MTI for additional information:

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Fuel Processing at MTI

Realistic Solutions to Real-World Problems

McDermott Technology, Inc. (MTI) is developing a family of fuel processors for fuel cells operating on a wide range of fuels. MTI, the research and development arm of McDermott International, began developing fuel processors in 1994. What began as an outgrowth of our solid-oxide fuel cell (SOFC) development activities quickly became a significant development program in its own right. Development of fuel processors draws not only on our fuel cell expertise, but also on our long corporate history in combustion and gasification of complex hydrocarbon fuels.

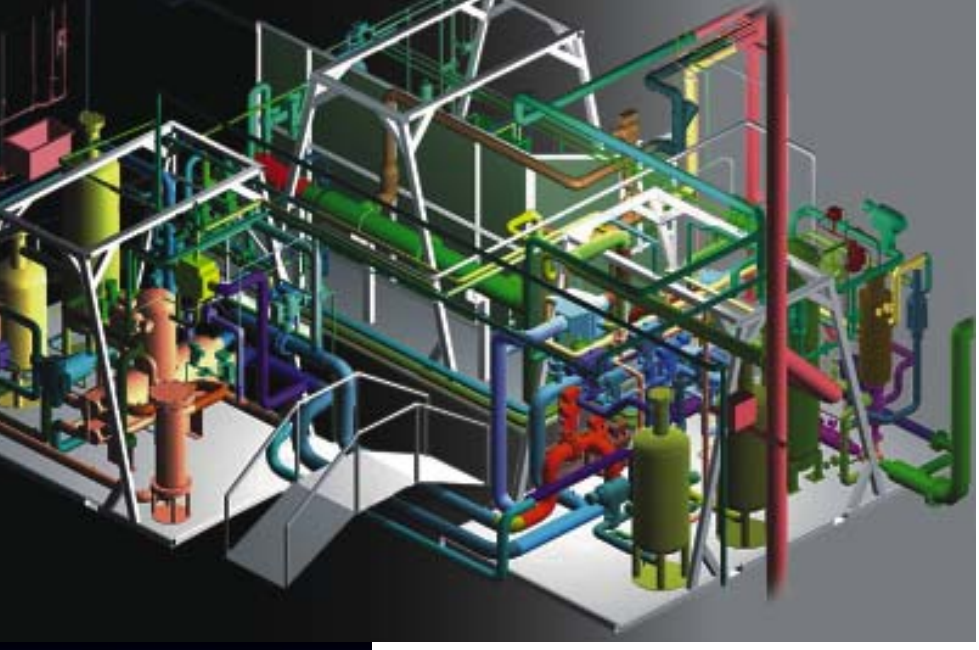
Since 1994, McDermott Technology has reformed many fuels, ranging from natural gas to gasoline to diesel fuel. Noncatalytic, partial-oxidation, catalytic autothermal, and steam reformers have all been employed. Through the course of our work, we developed special expertise in distillate fuel processing. This knowledge is being applied to the development of a 500-kW autothermal fuel processor for use in marine applications, a 50-kW multifuel processor for fuel cell electric vehicles, and a 10-kW LP reformer for a SOFC auxiliary power unit.

A summary of the major development programs undertaken or currently underway at MTI follows.

Sulfur-Bearing Gasoline, Methanol, and Ethanol – PEM Fuel Cell System

In 1999, the U.S. Department of Energy selected the MTI-lead team of MTI, Catalytica Advanced Technologies (CAT) and NexTech Materials, Ltd. to develop a fully integrated 50-kW catalytic multifuel processor suitable for automotive applications. We have developed a proprietary design that incorporates advanced, state-of-the-art reforming, liquid-phase desulfurization, and CO clean-up to achieve compact size, simplified controls, and high efficiency. Desulfurization of the gasoline is accomplished in a compact, replaceable canister. Fabrication of the system was completed in mid 2002 and testing is underway.

50-kW multifuel processor for automotive applications



500-kW integrated fuel processor test facility

Navy Distillate – PEM Fuel Cell Program

In 1998, MTI teamed with Ballard Power Systems and Gibbs & Cox to develop a proton-exchange-membrane (PEM) fuel cell generator for Navy ship-service power. Phase 1 of this program, sponsored by the Office of Naval Research (ONR), produced a system conceptual design of a 2.5-MW, ship-service fuel cell and demonstrated critical components under military marine conditions. Salt-air, shock, and vibration testing of PEM fuel cell stacks was performed. The autothermal reformer, in combination with hot-gas desulfurization and shift reactors, was operated on NATO F-76 naval distillate.

Although a complete PEM system was not selected for funding in Phase II of the program, MTI won a follow-up contract from ONR for conceptual design of a 500-kW integrated fuel processing system that produces PEM-suitable fuel gas. We were subsequently selected for an award from the Dual-Use Science and Technology Office to continue our development activities through final design, construction, and demonstration. Testing of the system will begin in 2003.

Natural Gas / Propane – SOFC Reformer

Cummins Power Generation and McDermott Technology, Inc. are collaborating on the development of a 10-kW SOFC power system for auxiliary power in recreational vehicles and commercial work vehicles, and for emergency power at remote telecommunication sites. Work is being performed with support from U.S. Department of Energy under its Solid-State Energy Conversion Alliance (SECA). The system is designed for liquid propane, but will also operate on natural gas. A catalytic partial-oxidation reformer was selected for use, since eliminating the need for steam simplifies design and reduces overall size, weight, and cost of the reformer.

Diesel Fuel – SOFC Development

In early 2001, McDermott Technology, Siemens Westinghouse Power Corp., and Phillips Petroleum Co. joined ranks to evaluate the feasibility of a solid-oxide fuel cell operating on commercial diesel fuel. Diesel-fired SOFCs have the potential to capture a significant share of the distributed power generation market where natural gas is not available and where dual fuel capability is desired. The effort brought together MTI's distillate fuel processing experience, the 40-year history of SOFC development at Siemens Westinghouse, and Phillip's fuels and hydrocarbon chemistry expertise. Development testing conducted by MTI at bench-scale and at 20 kW suggests that a system operating on diesel fuel with an efficiency exceeding 40% may be possible. Demonstration opportunities are currently being sought.

Logistic Fuel – Planar SOFC Demonstration

In 1997, under contract with the Defense Advanced Research Projects Agency and the Army Research Office, MTI completed a successful 300-hour demonstration of a proprietary, 50-kW, JP-8 fuel processor integrated with a planar, solid-oxide fuel cell. Our fuel processor achieved greater than 70% conversion efficiency, closely matching the maximum theoretical efficiency for that operating condition. The same system was demonstrated with high conversion efficiency using sulfur-laden naval distillate (NATO F-76), gasoline, and natural gas.

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